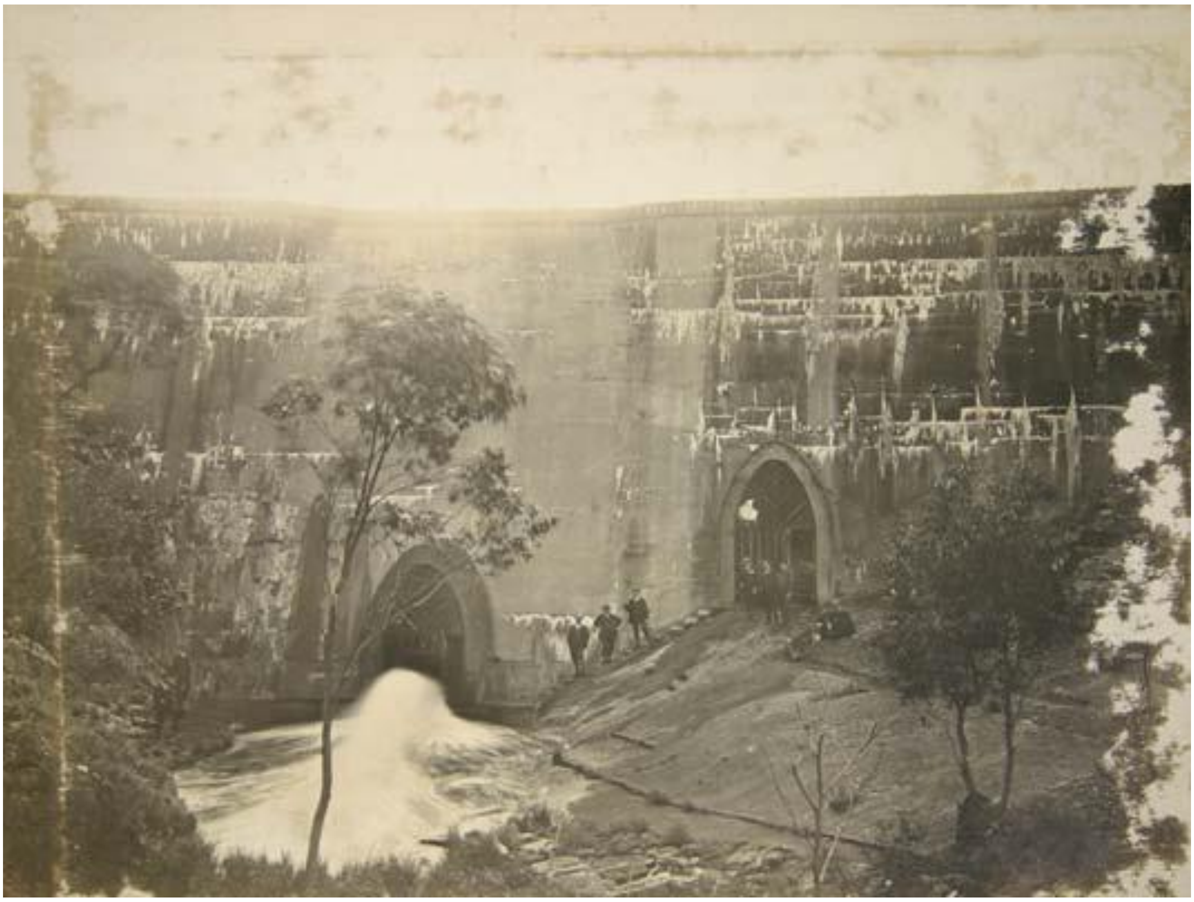
Engineers Australia
Engineering Heritage Australia
Engineering Heritage Victoria

Nomination for Engineering Heritage Recognition Program

Lower Stony Creek Dam



February 2018

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1 Introduction

The Lower Stony Creek concrete dam is a significant achievement for Australian engineering during the period of 1870-1880. As the third oldest concrete dam in the world, after Boyds Corner Dam (New York State, United States of America) and Lac de Perolles Dam (Switzerland), both constructed in 1872, and the oldest in Australia[1].

This concrete dam was constructed when Portland cement was not a well known material. The decision by Edward Dobson and George Gordon, to use Portland cement, was a remarkable step in accepting this material for large scale construction. Their dam design was also a significant move forward in designing a dam using civil engineering principles.

The dam wall is located in the Brisbane Ranges National Park, approximately 33 kilometres north from Geelong, Victoria, Australia. The mass concrete gravity dam was constructed over 18 months from 1873 to 1874. The structure stands 16 metres high and has a crest 68 metres long, with a storage capacity of 630 million litres. The reservoir was part of the water supply for Geelong from 1873 to 1998.

The decision to build this reservoir came from the failure in 1872 of the Upper Stony Creek Dam which was built to provide water to the developing town of Geelong.

The 146 year-old concrete dam on Lower Stony Creek has been nominated for recognition under Engineering Heritage Program for the following reasons:

- *It is first mass concrete dam in Australia and in the Southern Hemisphere which is still extant and in good condition.*
- *It was constructed with Portland cement at a time when this material had not been used extensively by engineers.*
- *It utilised stability analysis when that method was just beginning as a field, while previous dams were designed by craftsman engineers with little practical knowledge of statics.*
- *The dam design was modified by Edward Dobson and George Gordon in accordance with the recommendations of Professor W J M Rankine who advised on matters of dam safety and the economics of dam design. These recommendations are still relevant in modern dam design.*

[1] "*Lower Stony Creek Reservoir*", Brisbane Ranges National Park, poster

2 Heritage Award Nomination Letter

Learned Society Advisor
Engineering Heritage Australia
Engineers Australia
Engineering House
11 National Circuit
BARTON ACT 2600

Name of work: **Lower Stony Creek Dam**

The above-mentioned work is nominated for the award of an Engineering Heritage National Marker.

The dam is located in the Brisbane Ranges National Park north of the village of Anakie.

The grid reference is: 37.852761^{o} south, 144.246412^{o} east.

Owner: Parks Victoria, Level 10, 535 Bourke Street, Melbourne, Victoria 3000.

The owner has been advised of this nomination and a letter of agreement is attached.

Access to site: The site is a National Park and is open to the public.

The Nominating Body for this nomination is Engineering Heritage Victoria

David LeLievre
Chair
Engineering Heritage Victoria

Date: 25 February 2018

3 Heritage Assessment

3.1 Item name:

Lower Stony Creek Dam

3.2 Other/former names

Geelong Dam

Geelong's First Permanent Major Water Supply Works

3.3 Location

Brisbane Ranges National Park, north of Geelong, Victoria.
Coordinates: $37°51'9.8'' south,\ 144°14'47.48'' east$

Figure 1: Lower Stony Creek dam location (White dot)
Source: Google Map

3.4 Address

Brisbane Ranges National Park

3.5 Suburb/nearest Town

Anakie

3.6 State

Victoria

3.7 Local Government Area

City of Greater Geelong

3.8 Owner

Parks Victoria

3.9 Current Use

Retired Water Storage

3.10 Former Use

Water Supply Reservoir

3.11 Designer

George Gordon – Lead Design Engineer

3.12 Maker/Builder

Edward Dobson – Resident Engineer of the Geelong Water Supply Works.

3.13 Year Started

1873

3.14 Year Completed

1874
Geelong received water from the reservoir for the first time in 11.9.1873.

3.15 Physical Description

3.15.1 General description

The Lower Stony Creek dam wall is a gravity concrete dam that was built between February 1873 and June 1874, as a solution for the failure of the first dam (an earthfill embankment) at Upper Stony Creek. The new site was selected 6.4 km downstream from the Upper Stony Creek dam site. Until 1998, it provided Geelong with a reliable water supply.

It was engineered by George Gordon and Edward Dobson.

The dam wall is 16 m high and 69 m in length and the reservoir's storage capacity is 630 million litres. The width of the crest of the spillway is 0.84 m, which was considered as too thin to meet standards at the time of construction. The base width is 12 m at the point where the dam is tallest. The dam is triangular in cross section with a vertical upstream face. An

interesting feature of this gravity dam is its curve in plan with a radius of 91.4 m, as recommended by Professor Rankine[1]. The wall is set in sandstone and basalt rock[2], an essential advantage for its strength and stability.

3.15.2 Outlet Works

The outlet works consists of a pipe through the dam set well above the scour valve. The piping and valve-gear are located in an arch shaped enclosure protruding from the downstream face of the dam to the north of the scour valve and underneath the spillway. The roof of the arch protects the equipment from water overflowing the crest of the dam.

Figure 2: Outlet Works visible right of picture
Image: Cong Nguyen, 03/01/2017

3.15.3 Scour

A generous scour pipe is set at the lowest point of the dam wall to discharge built up sediment that deposits at the upstream base of a dam. It can also be used to lower the storage level if required. Located directly below the spillway crest, the arch structure protects the scour valve from spillway overflows.

[1] (Harper, 2016, p. 100)
[2] From observation on 3 February 2017

Figure 3: Scour operating
Source: Geelong Regional Library

3.15.4 Spillway

Spillways are structures that safely discharge flood water from a dam to a downstream river. Spillways can be either controlled or uncontrolled. Controlled spillways contain gates which can be lowered or raised, whereas uncontrolled spillways are often referred to as "fill and spill', as the dam releases water when the full capacity height is reached. Spillway capacity, or rate of discharge is controlled by the height of water above the spillway crest.. Lower Stony has an uncontrolled spillway, with a capacity of 77m^3/s .

3.15.5 Foundations

The foundation of the dam is keyed into the bedrock to resist sliding failure.

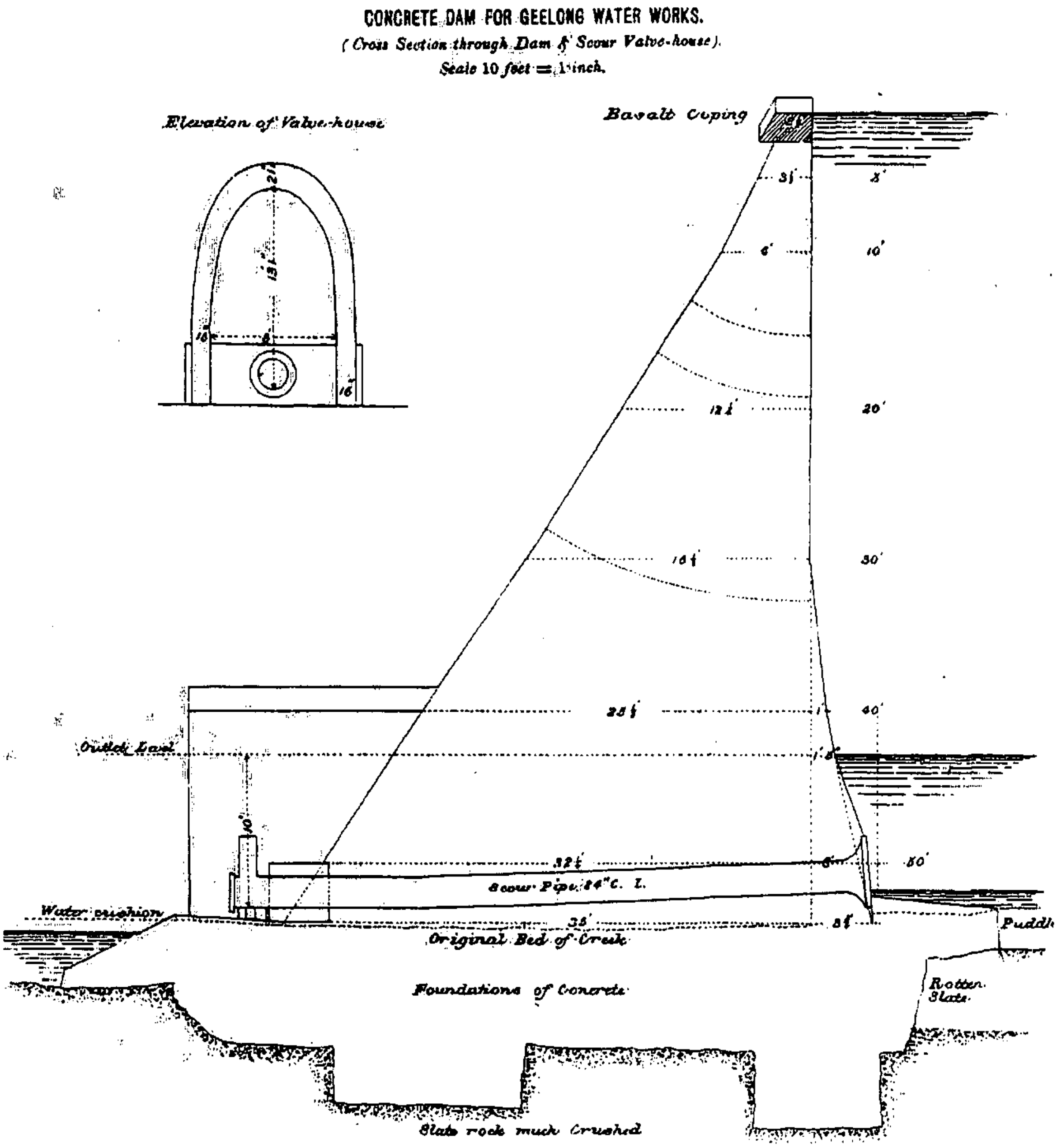

Figure 4: Profile of Lower Stony Creek Dam showing keyed foundation.
Source: (Harper, 1998, p. 87)

3.16 Physical Condition

The dam has been retired since1998, however it is still in good condition. The floor of the reservoir has been covered with bushes and trees as the reservoir has been empty for more than 20 years. The water level against the upstream face of the dam wall is less 4 m [1]deep.

[1] Measured on 3 February 2017

Figure 5: Spillway face of the Lower Stony Creek dam
Image: Cong Nguyen, 3 February 2017

Figure 6: Reservoir face of the dam wall
Image: Cong Nguyen, 3 February 2017

3.17 Modification and Dates

No information has been found regarding modifications to the dam. As the dam is in good shape structurally, and appears original, we believe no major modifications have taken place.

3.18 Historical Notes

3.18.1 The Upper Stony Creek Dam failure

Initially, Geelong's water supply was originally taken from the construction of an embankment dam on the Upper Stony Creek, recognised as the world's highest earthen dam at the time of construction. But problems began with the embankment dam in 1871. Significantly the embankment had sunk 1.45 m in the middle. The by-wash, or spillway channel had been excavated in soft schist which would erode quickly if used frequently. A leak in the tunnel under the embankment lost 1 ML of water daily[1].

Expert advice came from Colonel Richard Sankey of the Royal Engineers of India. Sankey reported that lack of sufficient and professional planning was to blame. "Haste and failure are synonymous terms when it comes to waterworks," he reported. Water must be patiently studied to secure success, he believed, as water was almost a living thing that "never makes a mistake"; it would find weaknesses in a design and make short use of it.[2]

In July 1872 water discovered the weaknesses in the structure and the embankment sunk 2.4 m. The embankment was declared unsafe and on 20 August 1872 the outlet valve was opened and all the water released.

The dam was allowed to come to a rest by March 1873. A new by-wash was cut, and the embankment was strengthened and reduced in height at the expense of total capacity - a reduction of 3400 ML to 760 ML. To augment the reduced capacity a decision was made to construct a new concrete gravity dam downstream. Built over 18 months, 1873-1874, the Lower Stony Reservoir had a storage of 650 ML resulting in a total capacity of 1410 ML for the Stony Creek system.[3]

The new concrete dam cost £17 000 and an extra £12 000 was spent on a new water pipe to convey water to Geelong.

Lower Stony Reservoir was created to fulfil a need brought about by hasty decisions and a lack of planning and some poor engineering practices.

3.18.2 Site Selection

The new site was chosen based on the size of storage that could be achieved, the ease with which a dam wall could be constructed and the nature of the ground where the dam wall was

[1] (Edmonds, 2005)
[2] (Edmonds, 2005, p. 46)
[3] (Edmonds, 2005, p. 48)

to be constructed.[1] After considering a few sites in the area, the lowest cost was adopted. Edward Dobson, as the Resident Engineer, who initially suggested the idea of constructing a new dam in the area, stated in his paper:[2]

> The present creek twists along the bottom of the valley sometimes following the line of strike at the foot of steep cliff, sometimes abruptly crossing the line of a reef through a rocky gorge; but, in spite of all the obstacles through which it had to cut its way, running on a nearly uniform gradient from the head of the Stony Creek to the plains at the foot of the ranges, …
>
> From the above readily understood that it is divided by the more important reeds into large basins, each having its outlet through a narrow gap in the reef which forms its lower margin, and which, like a ruined wall of ashlar masonry, rectangular blocks of stone lying strewn on the ground at its foot, as though chiselled by the hand of man and thrown down in their place by some convulsion of nature.
>
> Of these basins three appeared especially suitable for reservoir sites; and after making contour surveys and approximate calculations of the relative capacity of each for a given height of dam, the lowest cost option was selected for the site of the new storage reservoir. The site was fixed so that the whole of the dam should be founded on the reef".

3.18.3 Conceptual Design

As the new site was selected, its design was made by George Gordon, the newly appointed Chief Engineer for Water Supply (1871-1875). As an experienced engineer who had studied and worked across Europe, he designed the dam profile from a point of view of theoretical developments in the field. The dam was designed to have horizontal curvature in the wall as Gordon applied recommendations from Professor William J M Rankine on dam design.[3] As one of his proposed ideas was designing the dam wall with a horizontal curvature to avoid any horizontal tension in the air face. Taking this suggestion, the Lower Stony Creek Dam wall is curved in plan towards the reservoir with a radius of 91.4 metres. With this feature, the dam can also be known as one of the first dams to follow the ten current design principles based on stability and economy.

3.18.4 Construction Material

As there was a requirement for a spillway over the dam wall, its material had to be either masonry or concrete. The final decision involved both George Gordon, as Chief Engineer – responsible for design, and Edward Dobson, as Resident Engineer – responsible for construction. With the strong recommendation from Dobson, who was the person with the most experience in field construction, the dam was built with Portland cement concrete.

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[1] (Parks Victoria, 2000)
[2] (Dobson, 1871)
[3] (Rankine, 1872)

In his paper, Dobson explained the reasons for using Portland cement concrete over masonry. [1] Firstly, he considered the ability of concrete to be compacted into irregular shapes as to provide a key into the rock bed to increase resistance against sliding.

Secondly, to save time and money, he understood the fact that if hydraulic lime was used for the mortar, it would slow down the construction progress as hydraulic lime would take more time to set sufficiently for the work to proceed than was the case with Portland cement. Also, a quick-setting mortar was required because creek flows in the valley would submerge construction frequently.

Lastly, Dobson considered the complications that must be introduced to the bedding of the masonry, such as placing the blocks by toothing into each other. This is necessary because masonry, normally laid with horizontal courses, is not suitable for resisting the lateral thrust of water.[2]

Portland cement was a new material at the time in the 1870s. It was developed in Britain during the period 1820-1850, when manufacturers attempted to produce hydraulic cement to replace the Roman cement and Hydraulic lime.[3] By 1850, Portland cement had become a distinguishable product from hydraulic lime and Roman cement, however, the manufacturers were still trying to make a consistent product. For that reason, the cost of Portland cement was more expensive than other products in the construction field. The decision by Dobson to utilize Portland cement, was a remarkable step forward for British and Australian engineers.

3.18.5 Construction Techniques

Lower Stony Dam was constructed in an era when labour was cheap, employment was needed and specific expertise was not required. The concrete was mixed by hand.[4]

Concrete was mixed to the following volume proportions:

- Cement 1
- Sand 1.5
- Screenings 1.5
- 50 mm stone aggregate 4.5

This resulted in a concrete with a density of, 2300 kg/m^3 comparable to modern concrete mixes of about 2400 kg/m^3 ~.[5] The following procedure was implemented for construction:

> Cement and sand were mixed dry and then made into a mortar. The mortar was then thrown over the broken stone and mixed by turning it over and over until it formed a pulpy mass which was then placed in barrows.
>
> For the higher levels of the dam, the concrete was mixed in a horse driven pugmill located on a cliff platform above the dam. The concrete was transported to the dam

[1] (Dobson, 1871)
[2] (Harper, B. C. S., 1998)
[3] (Gandreau, et al., 2008)
[4] (Cole, p. 20)
[5] (see 4.3.2.1)

using double acting haulage boxes operating on an incline so that, as the full box slid down, the empty one was pulled back.[1]

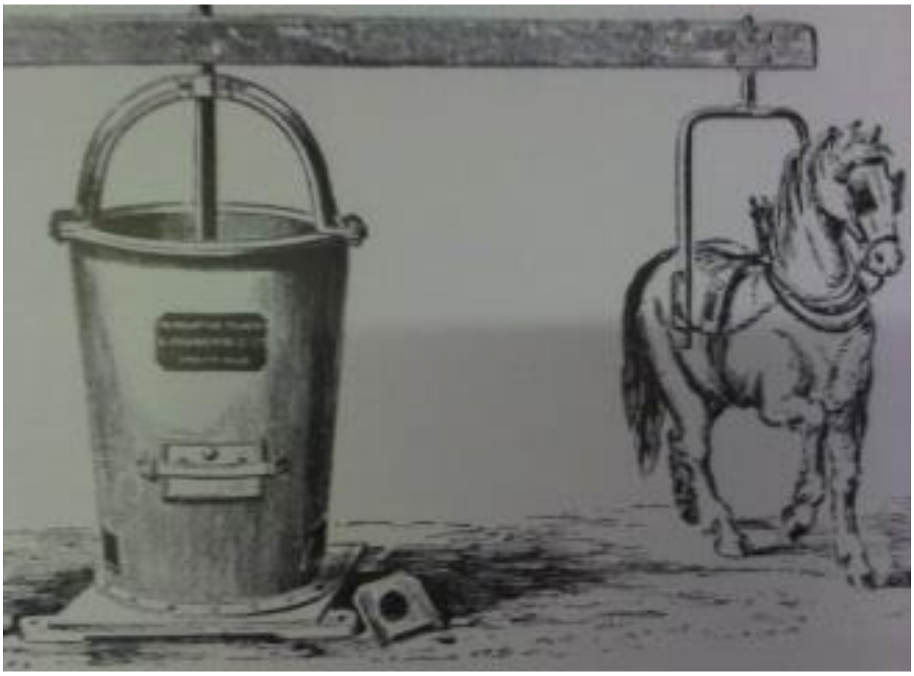

Figure 7: 19th Century horse driven pugmill for mixing concrete,
Source: http://www.brickdirectory.co.uk/html/brick_history.html

The concrete was laid in courses a few inches thick. Before concreting the next layer, the hardened previous layer would be watered, and spread with cement grout to limit pores developing. Finally, the dam was coped with blue-stone 1.0 m wide by 0.5 m deep, to protect against wave damaging the crest.[2]

3.19 Heritage Listings

Name: Victorian Heritage Database.[3]

Title: Geelong Waterworks – Geelong's first Permanent Major Water Supply Works, Stony Creek Water System

Number: B7410

Date: N/A

Level: State

[1] (Cole, p. 22)
[2] (Cole, 1999, p. 22)
[3] Extracted from http://vhd.heritage.vic.gov.au/search/nt_search

4 Assessment of Significance

4.1 Historical Significance:

The Lower Stony Creek Dam is of historical significance as it is the first concrete dam in Australia as well as the Southern hemisphere and the third one in the world. It was built soon after Boylds Corner and Perolles Dams, both being completed in 1872.

The decision of Edward Dobson to use Portland cement as the main material made a significant move in the Engineering field at the time. In 1870s, Portland cement concrete was still a new construction material, whose cost and labour requirement was too different for constructors and engineers to apply to large scale construction. This material was developed in the period 1820-1850 in Britain, however until the1900s, various manufacturers were still in the process of learning how to make a consistent product. Not until the late 19th century was Portland cement starting to be used largely in construction, both in Australia and globally.[1]

For 125 years, the dam has given Geelong “its first reliable water supply, essential for industrial commercial growth, public health and protection from fire” until its retirement in 1998.

4.2 Historic Individuals or Association:

Please prefer to Appendix B: Historic Individuals or Associations

4.3 Creative or Technical Achievement:

4.3.1 Portland Cement

At the time of construction 1873-1874, the idea of using Portland cement concrete for large scale construction was just a new alternative idea in the engineering field, especially for the British engineers. Its use at Lower Stony Creek Dam was a technical achievement for Australian and British engineers in accepting and training workers to use this material comfortably.

4.3.2 Design Loading Conditions

Dams, now, are designed for various loading conditions; Lower Stony Creek Dam was only designed for dead load, head water pressure, possibly silt pressure, and just missed out on the advancements made with uplift pressure.

4.3.3 Dead Load, Weight of the Dam

The weight of the gravity dam and its foundation is the mayor resisting and stabilising force of the dam. In two dimensional analysis of a gravity dam, the cross-section is segmented into simple shapes: rectangles and triangles. The resultant of all downward forces will represent the weight of the dam acting at the centre of gravity.[2]

[1] (Pavement-Interactive, 2008)
[2] (Ali, et al., 2011, p. 21)

The construction materials and the cross-section are the determining factors. The unit weight of concrete is used to calculate dead weight for stability analysis:[1]

$$\rho_w = 24.0\ kN/m^3$$

4.3.4 Head Water Pressure

Water pressure is the major external force acting on dams arising from hydrostatic pressure on the upstream face. For dams the hydrostatic pressure distribution is triangular, with the resultant force P, taken as the area of the distribution, acting $H/3$ from the base.

$$P = \frac{1}{2}\gamma_w H^2$$

Where:

$H = height\ of\ water\ contained$, and $\gamma_w = unit\ weight\ of\ water$

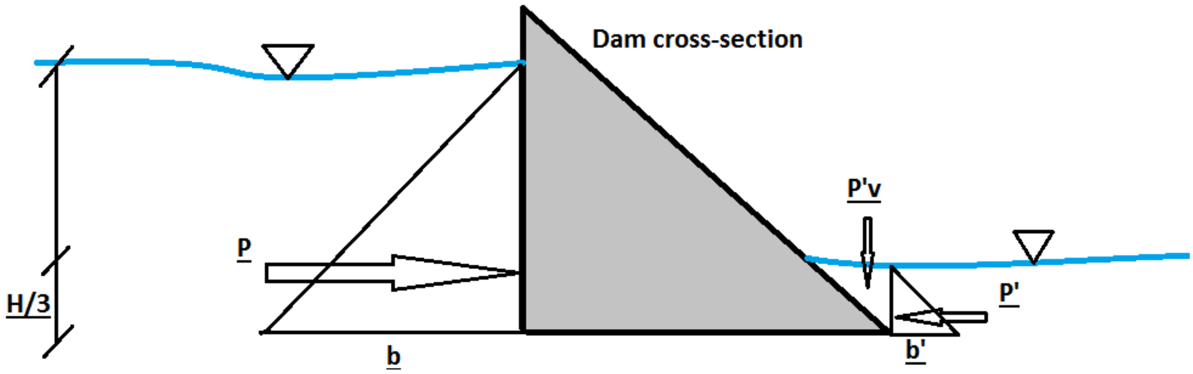

Figure 8: Force distributed on dam cross-section
Source: Jason King

The base of the triangular pressure distribution is $\gamma_w H$, giving the resultant P. Water pressure is calculated on the upstream side of the dam, and if tail water exists at the downstream. Submerged parts of the dam contain a vertical pressure, P'_v , equal to the weight of the column of tail-water acting at the centre of gravity downwards

4.3.5 Silt Pressure

It is so far unknown to us whether silt pressure was accounted for in the loading conditions of Lower Stony Creek Reservoir. Advancements in this field by Rankine existed at the time of construction. However, the build-up of silt was accounted for with the inclusion of a scour outlet to relieve silt build up. Silt gathers over time at the upstream face of the dam. If *h* is the height of silt deposited, then the additional force exerted by the submerged silt can be represented by Rankine's formula

$$P_{silt} = \frac{1}{2}\gamma_{sub}\ h^2 K_a$$

[1] (Chowdhury & Loo, 2014, p. 19)

acting at $h/3$ from the base

where, K_a is the coefficient of active earth pressure of silt

$$K_a = (1 - sin\varphi)/(1 + sin\varphi)$$

φ is the angle of internal friction of soil (cohesion is neglected)

γ_{sub} is the submerged unit weight of silt material

4.3.6 Uplift Pressure

Significantly, Lower Stony Creek Reservoir is not designed to account for uplift pressure as it was not a recognised factor until 1895, it is however a large part of designing modern dams.[1]

4.3.7 Dam Failure

Dams can fail in multiple ways: by overturning, compression crushing, tension, or sliding. Dams are constructed with these failure methods in mind.[2] Lower Stony Creek Dam was designed to be protected against the following failure mechanisms:

- Lower Stony Creek dam is protected against overturning by analysis of sections and the balance of overturning-moments and righting-moments.
- Compression crushing is taken into account, although the smaller size of the dam limits the need for detailed analysis to protect against crushing. Crushing isn't a factor in this dam.
- The dam is protected against tension failure and cracking by abiding by the middle-third rule of keeping the resultant of vertical and horizontal forces within the middle third of the dam in any section.
- Shear forces are negligible in any section of the dam, because of its small size. Lateral shear forces on any joint are low enough to be negligible.
- Sliding is protected against by "keying" the dam foundation into the bedrock.

[1] See Appendix E for uplift analysis of dams
[2] See Appendix F for detailed discussion on Dam Failure

4.3.8 Dam Profile

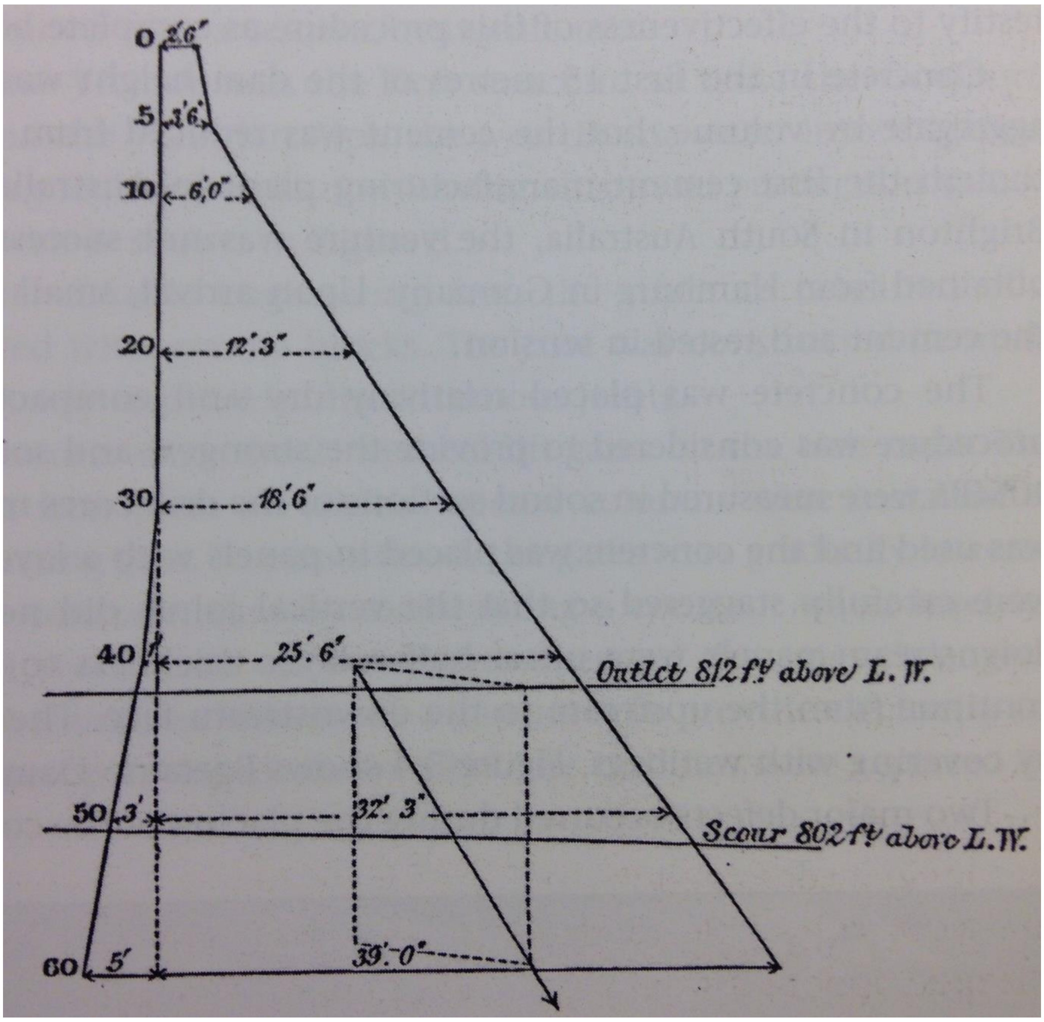

Figure 9: Hand-drawn cross-section of Lower Stony Creek Dam showing the location of the resultant, outlet and scour location
Source: *(Harper, 1998, p. 99)*

Interestingly the profile of the downstream face consists of a series of straights, rather than a logarithmic curve put forward by Professor Rankine.[1] Rankine said this form was excessive to depths less than 27m, Lower Stony Dam stands at 16m and therefore conforms.

The top-most section of the dam was relatively thin for its time and the standards used, being 840 mm thick. In comparison other masonry dams have a thickness of 3 m. It is also thin in regard to Rankine's suggestions in the design of masonry dams.[2]

4.3.9 Dam in Plan

Lower Stony Creek Dam is arched in plan. Arching increases the strength capacity of a gravity dam while reducing the materials required. Professor Rankine proposed that a dam could arch convex towards the reservoir so that horizontal tension doesn't develop on the

[1] See Appendix B
[2] (Harper, 1998)

downstream face of the dam. Although Gordon may have known about this recent development he only stated directly that: arching was implemented not for the added strength to resist the force of water contained by the reservoir, but so "...the ends might abut normally against the rock".[1] Calculations were made using a straight dam without taking into consideration the increased strength capacity created by arching.

4.3.10 Rational Design

The profile was a creative design by George Gordon. It was influenced by French engineering theory, which he states in his “Professional Papers on Indian Engineering”:

> I determined to construct a masonry dam on the French system of equal pressure. The formula used by Messrs. De Graeff and Delocre, was modified, however, so that the limiting pressure (8,000 lbs per square foot) was the pressure on the surface perpendicular to the rear slope of the dam, and the resultant of the pressure was made to cut the base of any horizontal section of the dam within the middle third of that base.[2]

Not just that, Gordon’s design also adopted Professor Rankine’s theory on how the curve on the dam helped to avoid any horizontal tension in the air face. However, in his report, he failed to acknowledge Professor Rankine’s recommendations.

With the adoption of Professor Rankine’s recommendations and the French engineering theory on dam design, the Lower Stony Creek Dam wall was the very first dam that adopted design techniques which are still applied until today. The decision on material also contributed to the technical achievement for the dam design.

4.3.11 Stability Analysis

Stability analysis was implemented in the design of Lower Stony Creek Dam, however it wasn't widely used in the design of other dams at the time. Lower Stony Creek Dam helped the civil engineering profession to move from craftsman to science based, in that it helped to introduce analysis into design. Previously dams had been designed by rule of thumb with little regard to force action.

Stability analysis was used to find the location of the resultant of all forces acting on the dam, to ensure it lay within the middle third of the dam. If this was not followed tension would develop between the base of the dam and the foundation at the upstream heel, leading to cracking and possible failure. The analytical method was used to safely design the dam.

4.3.12 Procedure of Analytical Method

The procedure simply uses moments and lever arms to find the eccentricity of the resultant:[3]

[1] (Harper, 1998)
[2] Please prefer to **Appendix D** for the location of the resultant force on the hand drawn cross-section of Lower Stony Reservoir
[3] (Tandon, 2014)

- *Select a unit length of the dam*
- *Sum all vertical forces, ΣV, and determine lever arm distance from the toe*
- *Sum all horizontal forces, ΣH, and determine lever arm distance from the toe*
- *Take the moment of all forces about the toe and find algebraic sum ΣM*
- *Find the location of the resultant force,* $\bar{X} = \Sigma M / \Sigma V$
- *Find eccentricity, e, of the resultant R*
- $e = \frac{B}{2} - \bar{X}$
- *Check that eccentricity lies in B/6 from the centre to ensure no tension develops in the dam*
- $e \leq \frac{B}{6}$
- *Determine vertical stresses OR normal stresses P_n at the toe and heel of the dam, this is the sum of the direct stress and the bending stress*
- $Pmax/min = \frac{\Sigma V}{B}[1 \pm \frac{6e}{B}]$
- P_n *should not exceed the crushing strength of concrete, between* $1500 - 3000\ kN/m^3$
- *Determine factor of safety against overturning*
- $Factor\ of\ Safety = \frac{\Sigma Rig\square ting\ Moments}{\Sigma Overturning\ Moments} = \frac{\Sigma M_r}{\Sigma M_o} \geq 1.5$
- *Determine the factor of safety against sliding*[1]

4.4 Research Potential:

A reasonable amount of work has been done by B C S Harper BE MSc PhD FIEAust CPEng – fellow, Department of History and Philosophy of Science, The University of Melbourne. In this nomination we have used Harper's papers *"Edward Dobson and the Mass Concrete Gravity Dam on Stony Creek for the Geelong Water Supply"* and *"Design Influences from France – George Gordon and the Lower Stony Creek Dam, Geelong"* in order to present the information on the design and construction of the Lower Stony Creek Dam. Although, the literature does provide information on certain aspects such as how the construction was carried out and the use of Portland Cement – there is still much work to be done to find out exact figures of labourers used, how the cement was transported and the way the concrete strength measured.

[1] Not used in the design of Lower Stony Creek Dam, although the foundation is keyed into the bedrock to resist sliding

4.5 Social:

One of the early sources of water supply in Geelong was known to be rain water which was stored using barrels. The other sources were "water obtained from wells or carted from the Barwon River".[1] The population growth of major towns in Victoria had increased during the gold rush of the 1850s. As a result it is known that clean water demand had also increased. However, a proper water supply system for Geelong had not commenced until June 1866[2].

The decision to build a water supply system for Geelong started with a fire incident at Singapore Terrace in March 1862, more than 14 000 gallons of water from Gray's fountain were poured on the blaze but nothing could be done to save the building.[3] From that, the Geelong Town Council decided to construct a water system for Geelong to assist with fighting future fires and to provide a water supply to the city.

After the failure of Upper Stony Creek Dam, the Lower Stony Creek Reservoir supplied water for Geelong town from 1873 to 1998. The Lower Stony Creek Dam made a huge contribution to Geelong's town water supply for nearly 125 years.

At the end of 1875, average consumption from the new system[4] was above 270 000 gallons a day, which equated to a daily average of 22 gallons per person based on 12 000 customers, including the railways, gas works and other factories[5]. By 1901, Geelong's population increased to 25 017[6], made it the fourth largest town in Victoria, after Greater Melbourne (496 079), Ballarat (49 414) and Bendigo (42 701).[7]

Clearly, the building of this concrete dam contributed significantly to Geelong's community, providing reliable potable water and protecting against fire risk.

4.6 Rarity:

In the period of 1870 -1880, a mass concrete dam was seen as a rare construction type in the world. Until 1880, there are only two concrete dam in Australia and four in the world: Boyds Corner Dam in the United State (1872), Perolles Dam in Switzerland (1872), Lower Stony Creek Dam in Australia (1873) and 75 Miles Dam south of Warwick in Queensland, Australia (1880).

4.7 Representativeness:

Lower Stony Creek Dam is representative of concrete gravity dams, especially early forms. It utilizes mass concrete and is unreinforced.

Lower Stony Creek Dam is the first mass concrete wall built in the Southern hemisphere. It represents innovation in concrete dams: utilizing Portland cement and theoretically based

[1] Report of the State Development Committee on The Geelong District Water Supply, 1949 Victoria
[2] Report of the State Development Committee on The Geelong District Water Supply, 1949 Victoria
[3] A local landmark of Geelong in 1862
[4] Before 1863, the Geelong town's main water supply was from Gray's fountain. After 1874, the old system came to rest and its pipeline was dug up and sold to the Government.
[5] *Edmunds,* 2005 page 50
[6] The Geelong's population in 1861 was 22 929 – before the new water system was introduced
[7] *Edmunds*, 2005, page 58

designs. The fact that it is extant and still functional is evidence of the importance of stability design.

4.8 Integrity/Intactness:

The Lower Stony Creek Dam is extant 125 years after its construction, without any known major modifications.

4.9 Statement of Significance:

4.9.1 Brief Statement of Significance by authors of this nomination

The Lower Stony Creek Dam is of historical, social and engineering significance.

It utilizes theoretically based principles of stability in its design at a time when this was uncommon and just beginning to be the norm. It helped stability analysis and the method of middle third to become the standard for gravity dam design.

It was constructed with Portland cement when this material was not common in construction. Lower Stony Creek Dam is the third concrete gravity dam constructed in the world. It contributed to the later normal practice of using Portland cement in large civil engineering structures.

It is of social importance to the Town of Geelong as it provided the growing city with potable water for many years and allowed the city to grow after the population boom of the Gold Rush period.

It is of National historical importance to Australia as our oldest concrete gravity dam.

4.9.2 Heritage Victoria

"The Geelong Waterworks has historic significance as the first permanent major water supply works serving Geelong and is among the earliest water supply systems constructed in Victoria. The system played a significant role in facilitating the development of Geelong to City status by 1910 and subsequently as an important manufacturing centre and port. It provided Geelong's only source of water supply for over 50 years and continued to operate in its entirety until the 1980's. Significant people associated with the Geelong Waterworks include Henry O Christopherson, engineer, proposer of the original scheme and later Chief Engineer of the Victorian Water Supply Department; George Gordon, design engineer of the Lower Stony Creek concrete dam; Lieutenant-Colonel Richard H Sankey, engineer, engaged by the Victorian Government to review the Geelong Scheme in 1871; Edward Dobson, Resident Engineer of the Geelong Water Supply Works; Charles Brown - Victorian Water Supply Department inspector for the Anakie district; and James S. Sharland, Engineer-in-Chief of the Geelong Waterworks & Sewerage Trust.

The Geelong Waterworks has scientific significance. The works, which were constructed over a period of seven years from 1866 to 1873, demonstrate original design qualities of the nineteenth century. Considerable engineering design and construction problems were surmounted in order to bring the system into operation. The dam forming the Lower Stony Creek Reservoir, completed in 1874, has been recognised as Australia's first mass concrete gravity dam.

The headworks and catchment area of the Stony Creek System lie within the Brisbane Ranges National Park which contains flora and fauna of State significance and two statutory Reference Areas that are used to maintain natural ecosystems. There are also many Aboriginal Places of State significance within the Stony Creek catchment area. There are 46 places registered on the Victorian Aboriginal Heritage Register, 3 scarred trees and 43 artefact scatters. The locations are Cowie Creek, Anakie Hills, Brisbane Ranges, Stony Creek and Stony Creek Reservoirs."[1]

4.10 Level of Significance:

The authors are recommending significance at Engineering Heritage National Marker level.

[1] Extracted from (Victorian-Heritage-Database, n.d.)

5 Interpretation Plan

5.1 Interpretation Strategy

The approach taken for the interpretation of Engineering Heritage Works is laid out in the latest version of EHA's "Guide to the Engineering Heritage Recognition Program" [1]. The interpretation will first be made by marking the works with an appropriate level of heritage marker. A ceremony will then take place which will unveil the marker as well as an interpretation panel which summarises the story and the heritage significance of the structure for the public to recognise.

The following plan provides a summary for the design of the proposed interpretation panel which includes the content, location and also the funding.

5.2 Event Date and Arrangements with Owner.

A notional date on a Saturday morning in September 2018 will be suggested to the Owner, Parks Victoria. Finalisation of a day will be largely up to Parks Victoria in coordination with EHV. A letter inviting Parks Victoria seeking approval for the marking of the site and assistance with funding and organisation of the event will be sent in March 2018.

5.3 The Interpretation Panel.

Parks Victoria will be asked to fund a standard 1200 x 600 high interpretation panel and steel stand. The panel and stand will be designed in accordance with the Guide to the Engineering Heritage Recognition Program.

The panel can be placed in a variety of locations between the car park below the dam and the clear area just below the dam wall. This will be negotiated with Parks Victoria.

5.4 Possible Interpretation themes for Interpretation Panel

The following themes could be accommodated on a standard panel together with maps, drawings and images appropriate to the themes:

- History of Geelong Water Supply
- History of Lower Stony Creek Dam
- Engineering Features of the Dam
- What is Portland Cement?

[1] The 2017 version is the latest available.

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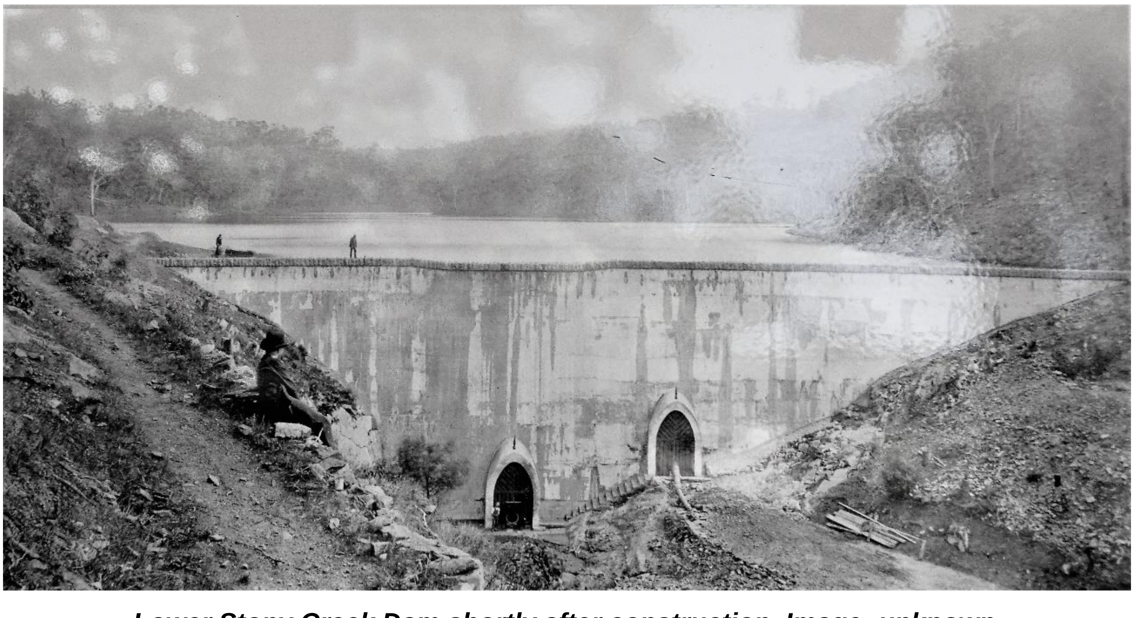
7.2 General Notes

This document has been prepared in accordance with the Commonwealth Government Style Manual for authors, editors and printers, Sixth Edition, revised by Snooks & Co, 2002.

8 Appendices

Appendix A : Images with Captions

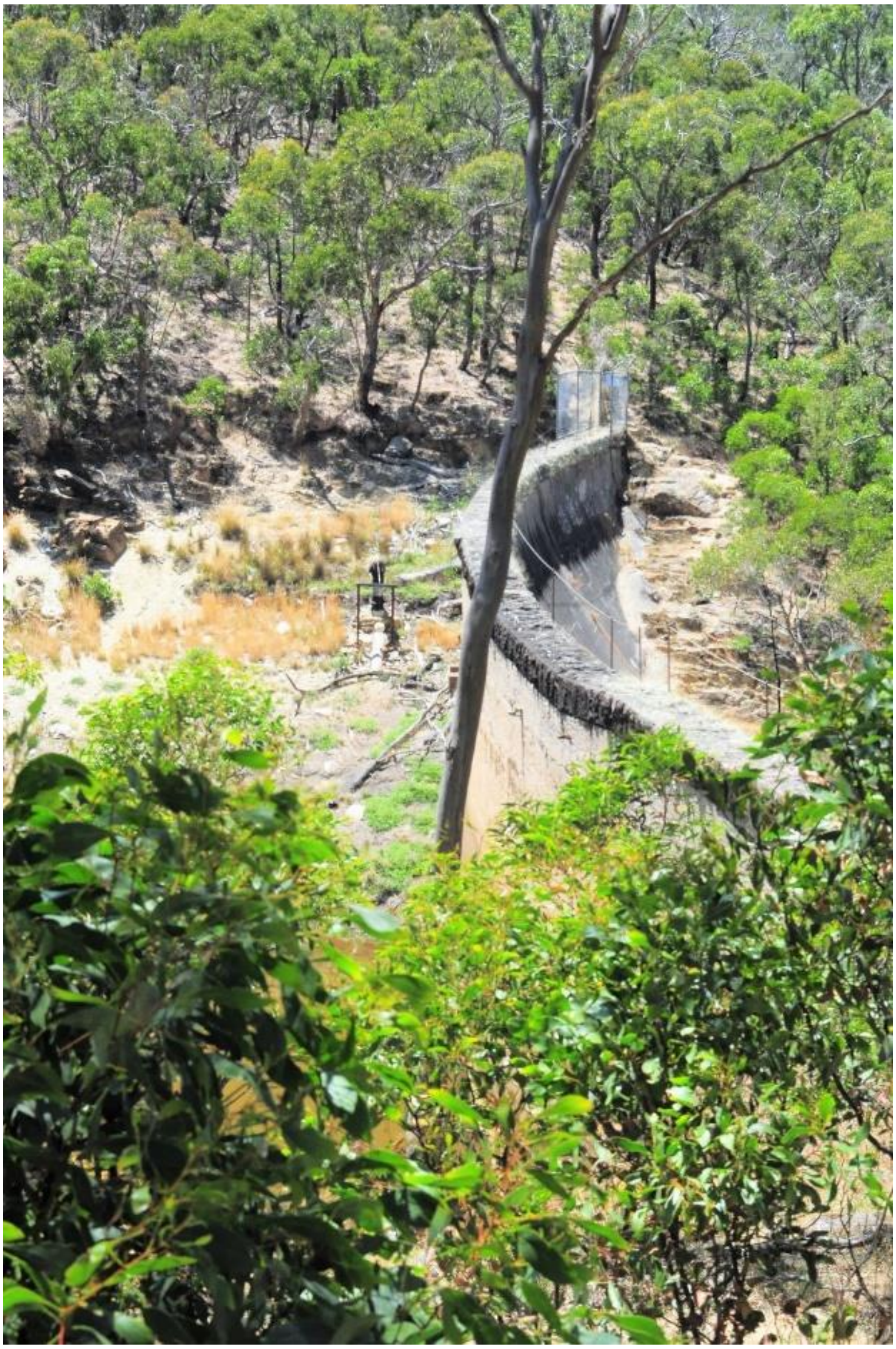
An old information panel that can be found near the dam spillway, about 400m from the dam wall. Most of the words have been worn off however the name “Lower Stony Creek Reservoir” is still visible. It also states that the dam was constructed in 1872 and some names of people who contributed in the construction. Image: unknown.



Lower Stony Creek Dam shortly after construction. Image: unknown.

Lower Stony Creek Dam, downstream face, 2013. Image: unknown.

Lower Stony Creek Dam, downstream face, January 2017. Image: Owen Peake.



Lower Stony Creek Dam, upstream face, January 2017. Note that dam has been decommissioned and is practically empty. Image: Owen Peake.

Lower Stony Creek Dam, small impoundment following decommissioning, January 2017. Image: Owen Peake.

Lower Stony Creek Dam, small impoundment following decommissioning, looking upstream from near the top of the dam wall over what would have been the reservoir, January 2017. Image: Owen Peake.

Lower Stony Creek Dam, downstream face, January 2017.
Two of the authors inspecting the dam. Image: Owen Peake.

Lower Stony Creek Dam, Dam outlet isolating valve,
January 2017.
Image: Owen Peake.

Appendix B : Historic Individuals or Associations

B1 Edward Dobson (1816-1908)

Edward Dobson. Image: Canterbury Museum, Christchurch, New Zealand.

"EDWARD DOBSON died at his residence near Christchurch, New Zealand, on the 19th April, 1908, at the advanced age of 91. He was one of the earliest settlers in the province of Canterbury, with which his name and services are indissolubly associated. His early experience may be briefly summarized.

Born in London in 1816 he was articled to Mr. Herring, a well-known London architect, and subsequently spent a sketching tour on the Continent to such profit that his drawings were exhibited in the architects' section of the Royal Academy.

After practising for some years on his own account as an architect and surveyor, at the same time studying engineering at University College, London, he was occupied between 1844 and 1850 on railway construction work on the staff of Mr John Urpeth Rastrick, a well-known railway engineer of that day.

In 1850 he sailed for New Zealand, where, with a few years' interval, the remainder of his long life was spent. It is unnecessary here to give in detail the history of his subsequent career, in as much as a vigorous and graphic account of his colonial experiences from Mr. Dobson's own pen will be found in an earlier volume of the Proceedings, and should be read in conjunction with this brief memoir.

From 1854 to 1868 he held the office of Provincial Engineer of Canterbury, and during this period he was responsible for all public works carried out in the colony. Some of these undertakings were described in a Paper on the public works of Canterbury, for which the Author received a Telford Medal.

The next seven years were spent in Victoria, Australia, where Mr. Dobson held charge for a time of the Melbourne and Hobson's Bay Railway. Subsequently he was appointed acting Engineer-in-Chief of the Victoria Water-Supply Department, in which capacity he carried out

the Geelong water supply works described in a Paper which he communicated to The Institution in 1878, and for which he was awarded a Telford premium.

Returning to New Zealand in 1876, Mr. Dobson settled down at Christchurch as a consulting engineer and carried on practice there until a few years before his death, from 1898 in association with his son, Mr. A. Dudley Dobson, the present city engineer of Christchurch. For nearly 6 years from 1887 he held the appointment of lecturer in civil engineering at Canterbury College.

He took great interest in the Volunteer movement, and held a commission; subsequently he joined the Engineers' Corps. Besides the communications presented to The Institution, he was the author of several works on engineering subjects, of which the best known is probably his work entitled "Pioneer Engineering," embodying the results of his own versatile experience. He held several offices in connection with local institutions in New Zealand, and was well-known and generally respected for his integrity of character and professional ability throughout the colony.

Mr. Dobson was elected an Associate of The Institution on the 1st March, 1842, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 29th March, 1881. He was thus attached to The Institution upwards of 60 years and was one of its oldest members." [1]

B2 George Gordon (1829-1907)

Image – none available

" George Gordon (1829-1907), engineer, was born at Arbroath, Forfarshire, Scotland, son of Robert Gordon and his wife Margaret, née Auton; the family home was Cargield House, near Dumfries. After apprenticeship in England with a consulting engineer he spent six years in Holland, four of them as chief engineer of the Amsterdam Water Co., and then served for ten years as chief district engineer of the Madras Irrigation and Canal Co. As a hydraulic engineer he offered his services to the Victorian government and in 1871 was asked to report on the public waterworks but the appointment was cancelled. In October the Duffy government opened fresh negotiations and on 5 May 1872 Gordon arrived in Melbourne to become chief engineer of the lands and works board. On 2, February 1875 he became chief engineer of the water supply department and held the post till Black Wednesday, 9 January 1878. His dismissal was raised in parliament and he petitioned the governor and the Queen for reinstatement and compensation but to no avail.

In 1880 Gordon was appointed to a water conservancy board to report on supplying water to the northern plains of Victoria for stock and domestic purposes…. The board concluded that the best means of supplying water was by using the natural channels and building cheap works for diversion and storage under the control of local trusts. These principles met with spirited opposition from advocates of large-scale irrigation such as Hugh McColl but became the basis of the Victorian Water Conservation Act of 1881 and later legislation in 1883-84. The board was then dissolved and Gordon was virtually dismissed….

[1] Extracted from http://www.gracesguide.co.uk/Edward_Dobson

In the next two decades Gordon managed his own engineering firm, consolidated the wealth he was amassing in private ventures, worked occasionally for the lands and works board and was consulted by the governments of Tasmania and New South Wales. He continued his interest in water schemes and in 1889 was a founding partner of the Lake Boga Irrigation Co. He also held land in the Chaffey Bros' scheme at Mildura….

He died aged 78 at his home, Ellerslie, Toorak, on 25 February 1907."[1]

http://adb.anu.edu.au/biography/gordon-george-3637

B3 Professor William John Macquorn Rankine (1820-1872)

Rankine was a Scottish mechanical engineer who contributed to civil engineering, specifically active/passive soil pressures, retaining walls, geomechanics, and structural engineering. He advanced the idea that tension should not be allowed to develop at any section of a dam, and for this to happen developed the 'middle third rule'. That the resultant of all forces acting on the dam should intersect the base, or any section through the dam, in the middle third of the base width.

Professor Rankine. Image:
https://commons.wikimedia.org/w/index.php?curid=4730900

Comment: Haven't found the reliable sources for the biographies of the people listed below:

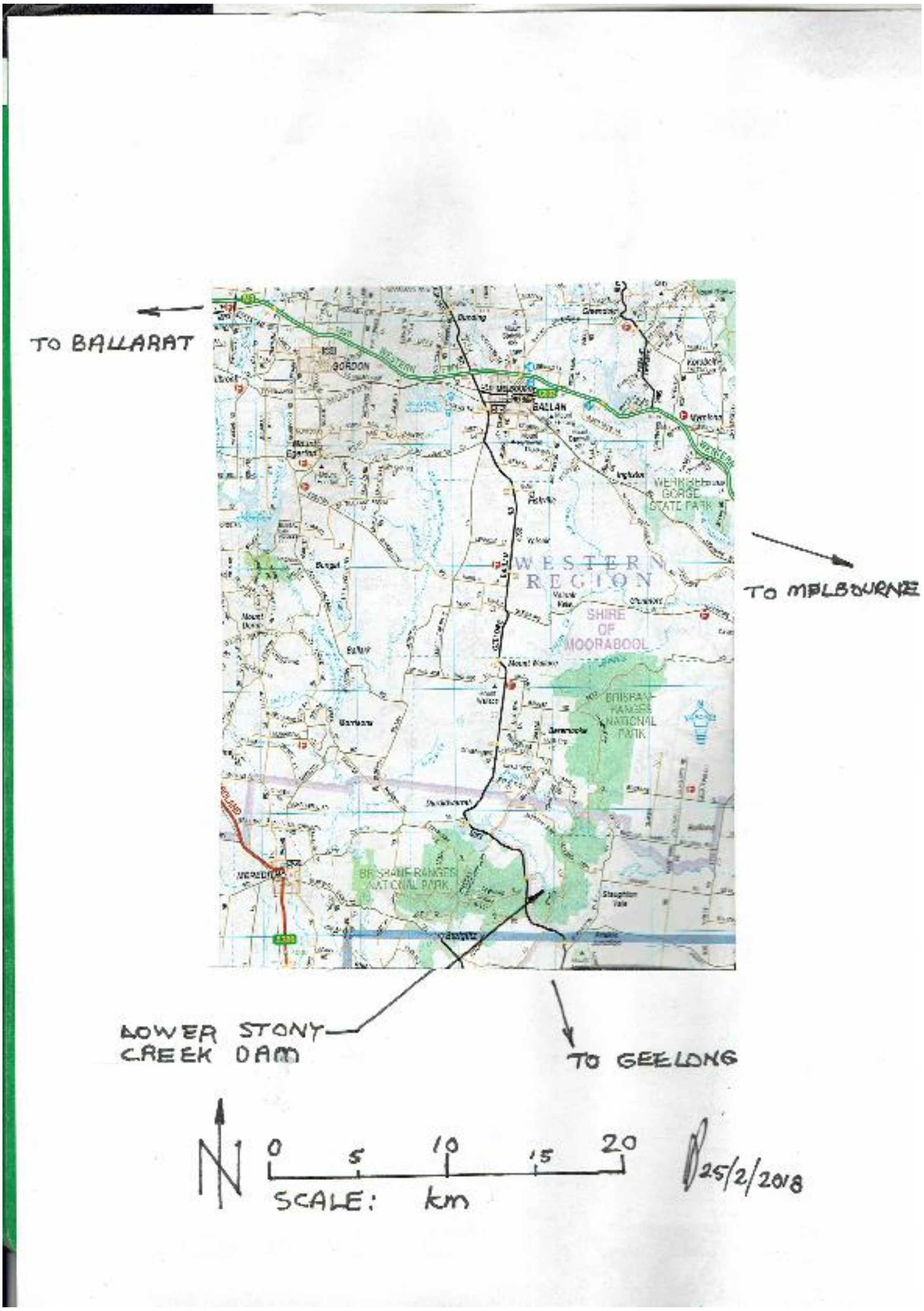
Henry O. Christopherson – Engineer, who proposed the original scheme.

Richard H. Sankey – Engineer, who was 'engaged by the Victorian Government to review the Geelong scheme'.

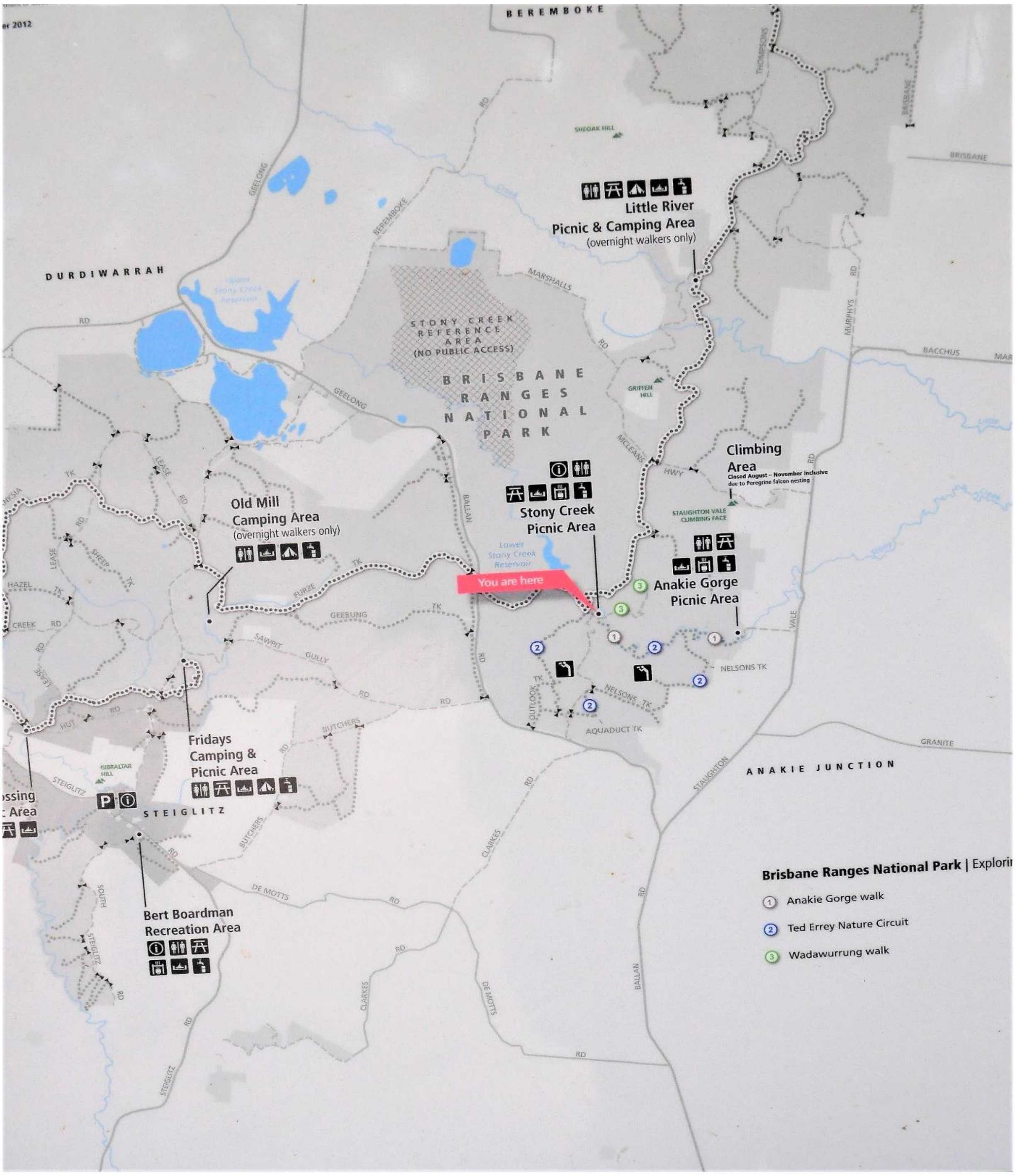
Charles Brown – Victorian Water Supply Department inspector.

[1] Extracted from http://www.gracesguide.co.uk/George_Gordon_Page

Appendix C : Maps



Locality Map. Brisbane Ranges National Park.
Image: RACV-Vicroads Country Directory Map 77.



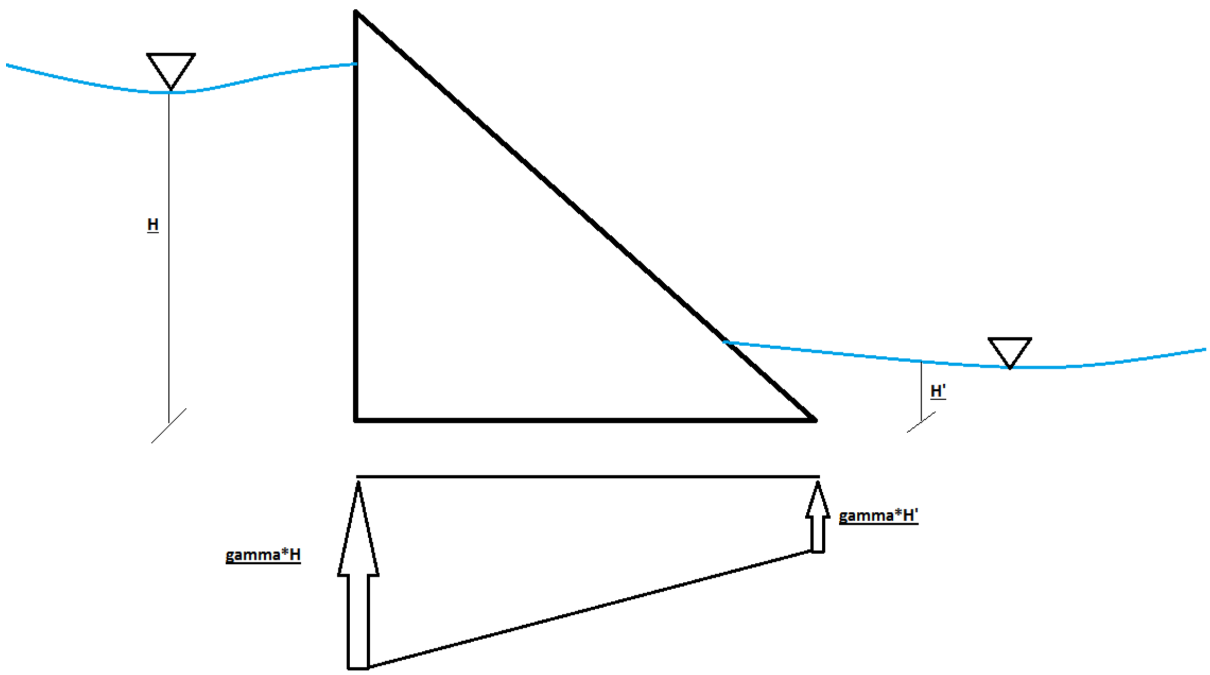
Map of Brisbane Ranges National Park. Stony Creek Picnic Area marked with red arrow. Image: Parks Victoria.

Appendix D : Uplift Pressure

Force is exerted on the base of the dam by uplift pressure. Water seepage through the pores and cracks of the foundation materials, and water seepage through the dam body and through the joints between the body and the foundation create uplift. Uplift is the second major force acting on a dam. Uplift reduces the effective weight of the dam, thereby reducing stability. Thus it must be accounted for in calculations.

The uplift pressure distribution exerted on the base of the dam is equal to the hydrostatic pressure at the heel joined by straight line to the hydrostatic pressure at the toe. Seepage galleries may be used to relieve uplift.[1]

Significantly, uplift was not figured into the design of Lower Stony Creek dam, as it was not a recognised factor until 1895.[2] This makes Lower Stony one of only a few extant dams not designed for uplift. Perhaps because of Dobson's high factor of safety at the time, allowed the dam to still exist today without this fundamental factor.



Since height of water is the only variable in calculations, the cross-section of the dam has been simplified. The above diagram shows the triangular uplift pressure distribution for a dam with tail water; when there is no tail water, uplift is zero at the toe of the dam.

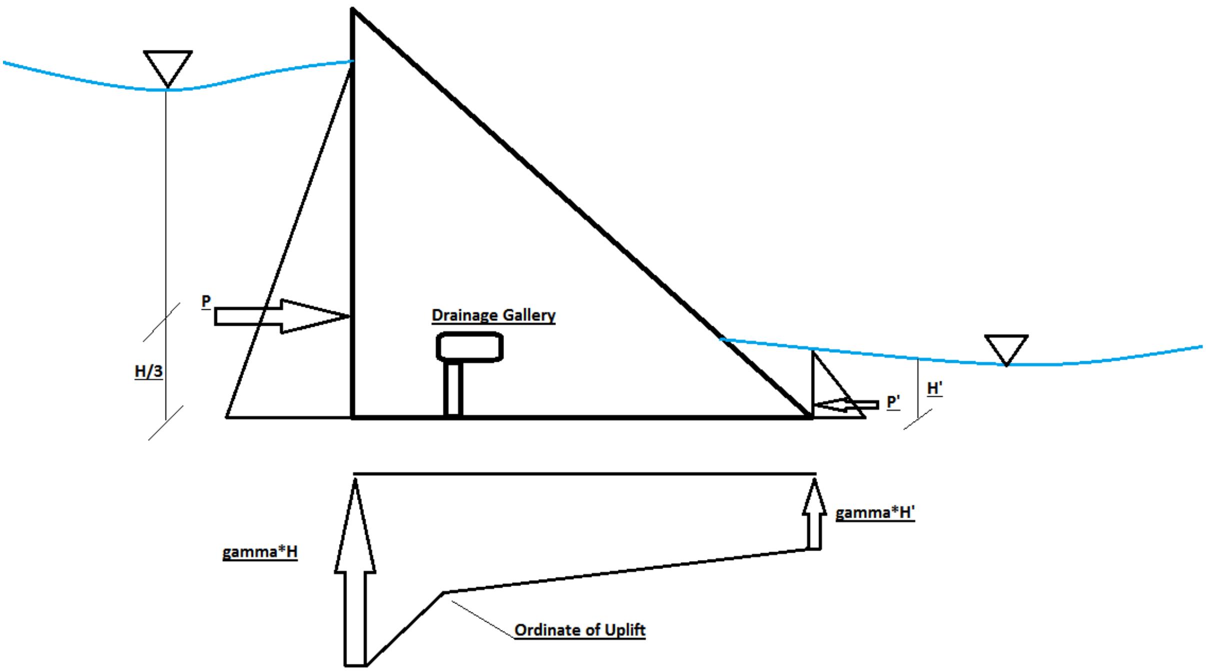
[1] (Ali, et al., 2011)
[2] (Dobson, 1871)

When a drainage gallery is provided, the ordinate of uplift is:

$$Ordinate\ of\ Uplift = \gamma_w H' + \frac{1}{3}(\gamma_w H - \gamma_w H')$$

Where $\gamma_w = unit\ weight\ of\ water,\ \ 9.807\ kN/m^3$

That is, ordinate of uplift is equal to the uplift at the toe plus one third of the difference between uplift at the heel and uplift at the toe. The ordinate of uplift occurs at the face of the gallery.



Appendix E: Dam Failure

Overturning

Overturning about the toe occurs when the resultant of all forces acting on the dam passes the toe, causing the dam to rotate about the toe, although in practice compressive forces will cause the dam to fail before overturning. The factor of safety of righting moments to overturning moments is generally 2 - 3.

Compression or Crushing

Crushing happens when compressive stress exceeds the strength of the dam material or the foundation, and dam fails.

The vertical direct stress distribution is given by:

$$Pmax/\min = \Sigma\frac{V}{B}[1 \pm \frac{6e}{B}]$$

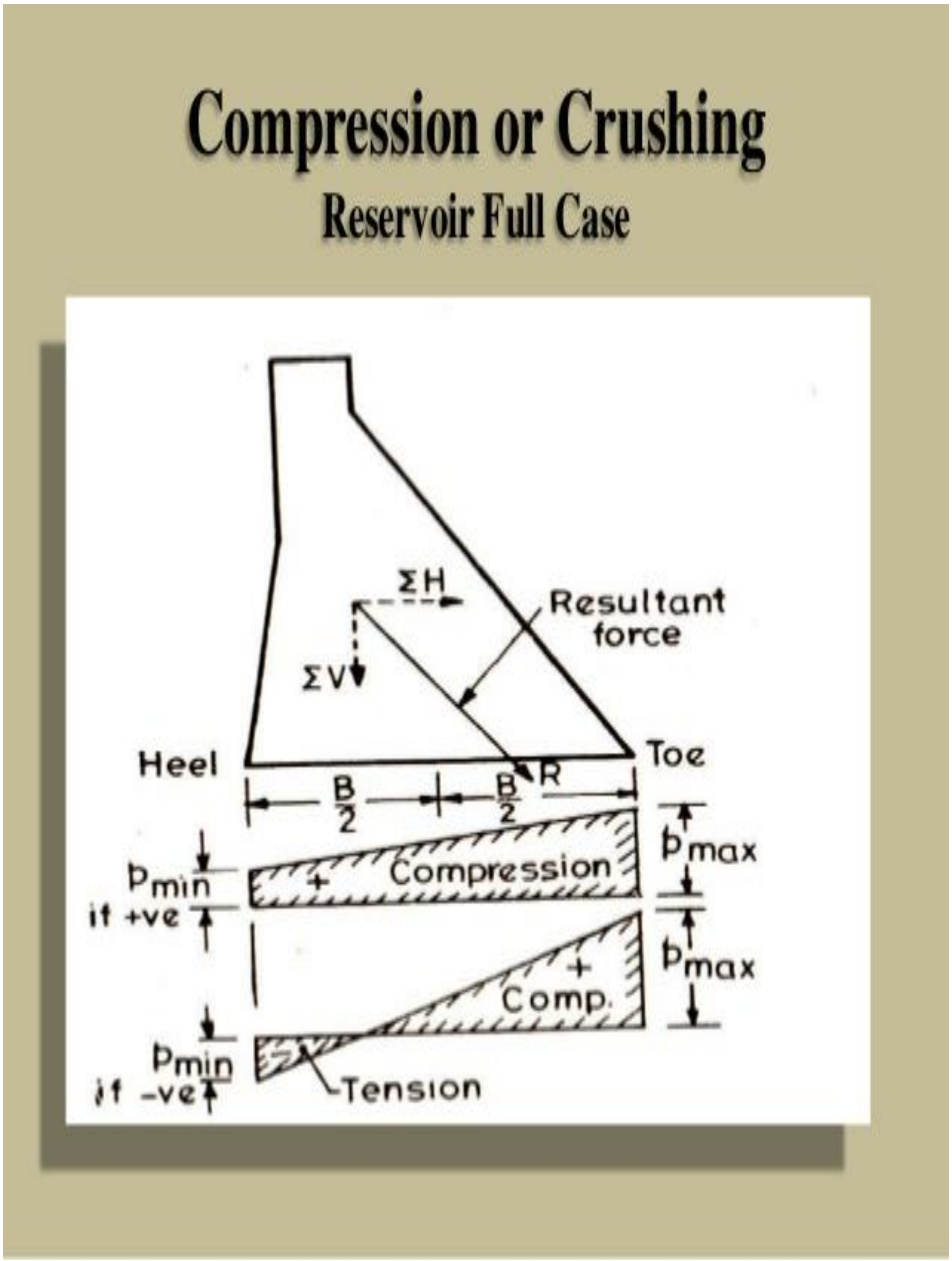
Where,

e = eccentricity of the resultant force from the centre of the base

ΣV = Total vertical force

B = Base width

The crushing strength of concrete varies between: $1500\ to\ 3000\ KN/m^3$



Vertical stress distribution and location of the resultant force image :

http://www.slideshare.net/gauravhtandon1/gravity-dam

Tension

Concrete gravity dams are designed so that tension doesn't develop in any section. This is because of the strength of concrete is poor in tension. Tension loading can lead to cracking and water pressure can enter the crack.

To ensure tension is not developed anywhere on the base it is optimal that the vertical stress, Pmin > 0. As seen in the above diagram when Pmin < 0 tension develops between the foundation and the base of the dam.

$$\text{Pmin} = \frac{\Sigma V}{B}[1 - \frac{6e}{B}] \geq 0$$

Taking Pmin = 0

$$0 \leq \frac{\Sigma V}{B}[1 - \frac{6e}{B}]$$

$$1 \leq \frac{6e}{B}$$

$$\text{e} \leq \frac{B}{6}$$

That is the eccentricity must lie in $1/6$ of the base width either side of the centre for tension not to develop. This means the resultant of all forces acting on the dam, horizontal from the weight of the water, vertical from the dam self weight and uplift pressure, must lie within the middle third from the centre of the base. This is often referred to as the 'middle third rule'.

Sliding or Shear

Sliding failure will occur when the horizontal forces at any section in the dam exceed the frictional resistance developed at that section. Since Lower Stony is a smaller dam the effects of lateral force on joints is negligible, only sliding needs to be checked. Therefore the simplified equation will suffice, ignoring cohesion. ΣV is the sum of dam weight and uplift

$$1 < \mu\frac{\Sigma V}{\Sigma H} = FOS$$

Where, μ = 0.65 to 0.75

That is the ratio of friction developed between two surfaces needs to be greater than the horizontal force.

CHANGE CONTROL

VERSION 5	**05 MAY 2017**	**FIRST EDIT OF STUDENT FINAL COPY BY OP**
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